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# SCIENTIFIC INSTRUMENT PACKAGE

## FOR THE

# LARGE SPACE TELESCOPE

(NASA-CR-130214) SCIENTIFIC INSTRUMENT PACKAGE FOR THE LARGE SPACE TELESCOPE (SIP) Final Project Summary Technical Report (Kollsman Instrument Corp.) 37 p HC $4.00 CSCL 20F G3/14 N73-22394 Unclas 69296

Prepared for :

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SUMMARY TECHNICAL REPORT

# INSTRUMENTS FOR A LARGE SPACE TELESCOPE (SIP)

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December 1972

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Greenbelt, Maryland 20771

I

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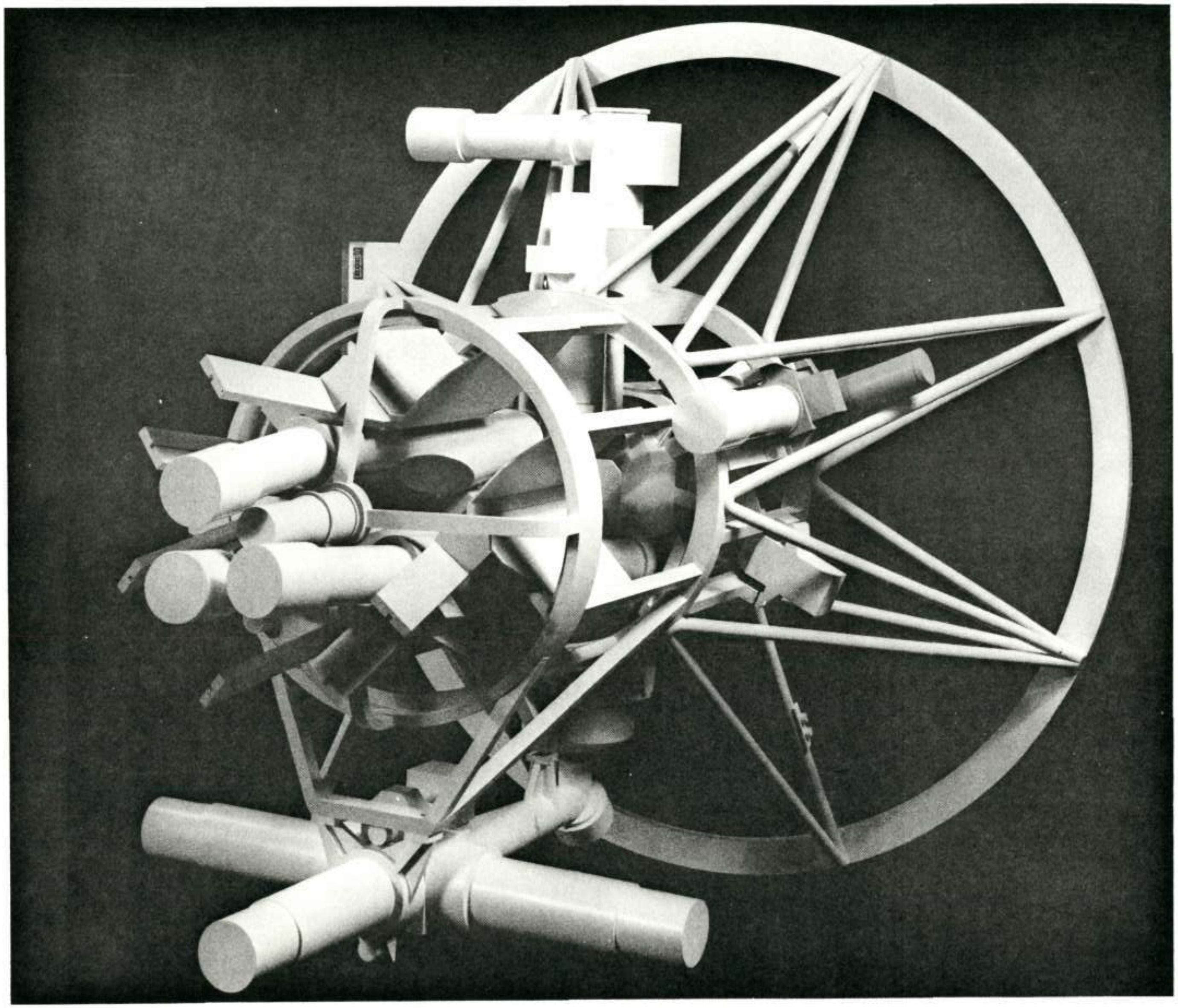


Scientific Instrumentation Package Aft View

Kollsman Instrument Corporation

# Section 1

# INTRODUCTION

This document is a summary report of the study performed by the Kollsman Instrument Corporation under NASA Contract No. 5-23068. The details of this study, of the Large Space Telescope Scientific Instrument Package, are contained in Volume IV of the NASA final report for the Phase A LST study titled "Instruments for a Large Space Telescope". The objectives of the study were:

1. To establish the feasibility of a Scientific Instrument Package (SIP) that will satisfy the requirements of the Large Space Telescope,

2. To establish a reference configuration which will serve as a study model,

3. To develop a body of data which will aid in the trade-off studies which will lead to the final design configuration.

The instruments that are described herein as making up the SIP are selected from those presented in the Goddard Space Flight Center report X-670-70-480 titled "Instrument Package for a Large Space Telescope". Design updates were made to meet both the scientific requirements of the steering committee and the many program requirements for a practical, maintainable LST. Design optimization of each instrument was not attempted at this time.

The Large Space Telescope will be a general purpose optical facility which will collect photons from selected celestial bodies for analysis by astronomers. The Scientific Instrument Package will take the energy collected by the telescope and provide the instruments to analyze this data with a high degree of precision. The LST will be in operation for at least 10 years; accordingly the SIP design will be flexible to permit on-orbit growth and change in accordance with the astronomy community requirements.

The Phase A study was guided by the preliminary requirements defined by the LST Science Steering Committee. The Committee recommended that the SIP provide high spatial resolution imagery throughout the range from Ultra Violet to Near Infra-Red, High Spectral Resolution Spectrography in the UV, and Faint Object Spectrography throughout the range from Ultra-Violet to Infra-Red (see Table 1).

Other guiding objectives were to make maximum use of the near diffraction limited performance of the telescope and the guidance and stability capability of the observatory. In addition, the instrument complement is selected to provide the user scientist the most flexible choice in selecting those instruments most suitable for carrying out the observation of interest. It is anticipated that during Phase B the astronomy community will establish the specific performance requirements of the LST. These requirements will become the basis for the final Performance Specification for the SIP. It is very likely that throughout the long life of the LST program additional requirements will be generated by the astronomy community. The SIP will be designed to be sufficiently flexible to permit the addition of instruments and/or the substitution of instruments on-orbit.

During the Phase A study it was premature to develop an optimized SIP configuration; it was appropriate to develop a reference model which would serve as a design guide, a "straw man" which would serve as the basis for trade-off studies.

A system development approach was used to define instruments to perform as an integral part of the LST including considerations of the telescope, support systems, interface, structure and on orbit maintenance. Exhaustive configuration analyses were not performed, but several configurations were evaluated and parametric studies were made to identify a configuration for use as the reference model. In addition to functional and operational requirements, vacant space was provided at the focal plane for future instruments and to facilitate maintenance.

The reference configuration developed shows that the SIP required to accomplish the preliminary scientific objectives is entirely feasible in the 1970's time frame, and that no new basic research is required. Several technical areas have been identified as needing further study to bring them to a suitable level of development, and these are stated in section 6. A configuration with provisions for in flight maintenance and updating has evolved, and reliability calculations indicate that a highly reliable SIP can be provided. When the final specific performance requirements are established, and instrument definition is provided for the phase B study, an in depth configuration analysis will be appropriate. That analysis can utilize the information and parametric data developed during this phase A study.

Table 1

SUMMARY LST STEERING COMMITTEE RECOMMENDATIONS

| Instrument | Resolution | Operating Range | Notes |
|---|---|---|---|
| | PRIMARY OBJECTIVES | | |
| I. High Spatial Resolution Camera | Match Telescope Performance | 110 to 1,100 nm | Largest Field Consistent with Detector Capability-Selectable Filters |
| II. High Spectral Resolution Spectrograph | $\frac{\lambda}{\Delta\lambda} = 3 \times 10^4$ | 110 to 350 nm | Slit Size Adjustable Max 72 x 72 μrad |
| III. Low Spectral Resolution Spectrograph | $\frac{\lambda}{\Delta\lambda} = 10^3$ | 110 nm to 5 μm | Slit Size Adjustable Max 72 x 72 μrad |
| | SECONDARY PRIORITY OBJECTIVES | | |
| IV. Very High Spectral Resolution Spectrograph | $\frac{\lambda}{\Delta\lambda} = 3 \times 10^5$ | - | |
| V. Polarimeter | - | ultraviolet | |
| VI. Photometer | TBD | - | High time resolution at $\Delta t \approx 1\text{-}10$ μsec |
| VII. Low Spatial Resolution Camera | | UV to 3-5 μm | |

## Section 2

## OVERALL SIP DESCRIPTION

The Scientific Instrument Package is an energy selecting, analyzing and processing system that has been tailored to match a 3 meter diameter, f/12 Ritchey-Chretien type telescope. Energy reaching the focal plane is selectively imaged on a variety of cameras or spectrographs. The design of the individual instruments is the result of preliminary trade-off studies of several system configuration concepts and is used as a reference configuration for interface evaluation with OTA and SSM. Figure 2-1 is a functional block diagram of the SIP. Two camera types are shown, one providing high spatial resolution of 160 nrad ($3.3 \times 10^{-2}$ arc sec) in a 0.173 mrad (36 arc sec.) field of view, the other with a resolution of 840 nrad ($17.5 \times 10^{-2}$ arc sec.) and a field of view of 1.39 mrad (4.8 arc min). Both cameras are located in the forward radial bay. See figure 2.2.

Two high resolution spectrographs, located in the rear axial bay, provide spectral resolution equal to or greater than $3 \times 10^4$ over the 115nm to 350nm spectral range. Four units provide faint object spectrography over the range of 115nm to 5um. The forward radial bay contains three of the units; the rear axial bay contains the fourth.

The general SIP configuration is shown in Figure 2-2. The basic structure consists of three (3) rings which are tied together by trusses to provide bending and torsional stability. The stability of the structure is independent of the rigidity of the instruments. The instruments have been systematically arranged to allow for the removal of an individual instrument without disturbing any other. Self-aligning devices and insertion guiderails are provided for replacing instruments in order to minimize the need of astronaut dexterity and specialized maintenance skills. The rear axial bay provides a growth capability for adding a supplemental, redundant or "yet to be conceived" instrument, besides those explicitly included in the complement described herein.

In addition to the scientific instruments there is a slit jaw camera and two active assemblies. The slit jaw camera provides the means for acquiring and maintaining the target image within the slit of the spectrographs, the spectrograph selector directs the target energy beam to the desired aft spectrograph; the aft spectrograph slit mechanism sets the entrance slit widths for the aft instruments. All forward radial bay spectrographs have individual, integral slit mechanisms.

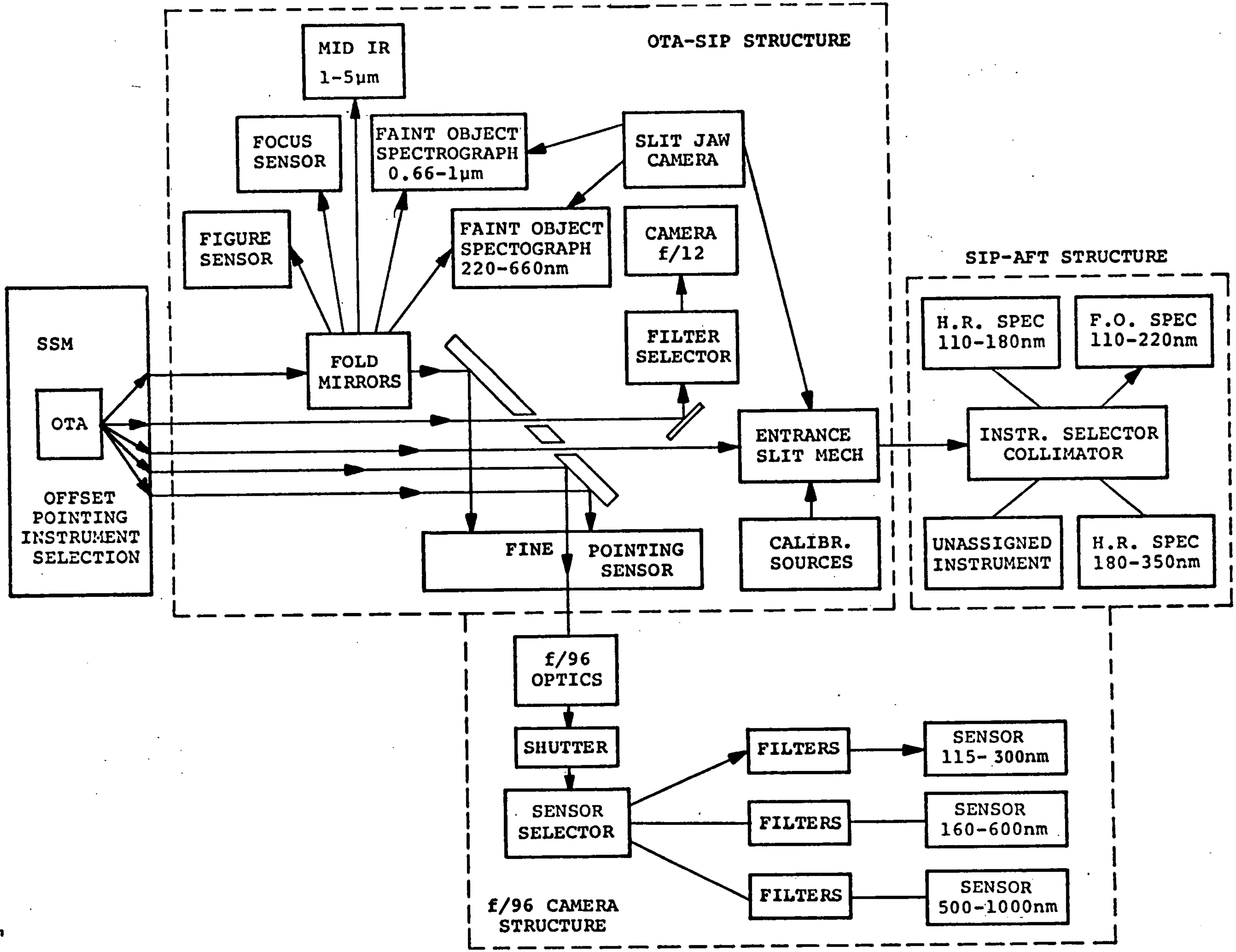



Figure 2.1. Scientific Instrument Package Functional Block Diagram

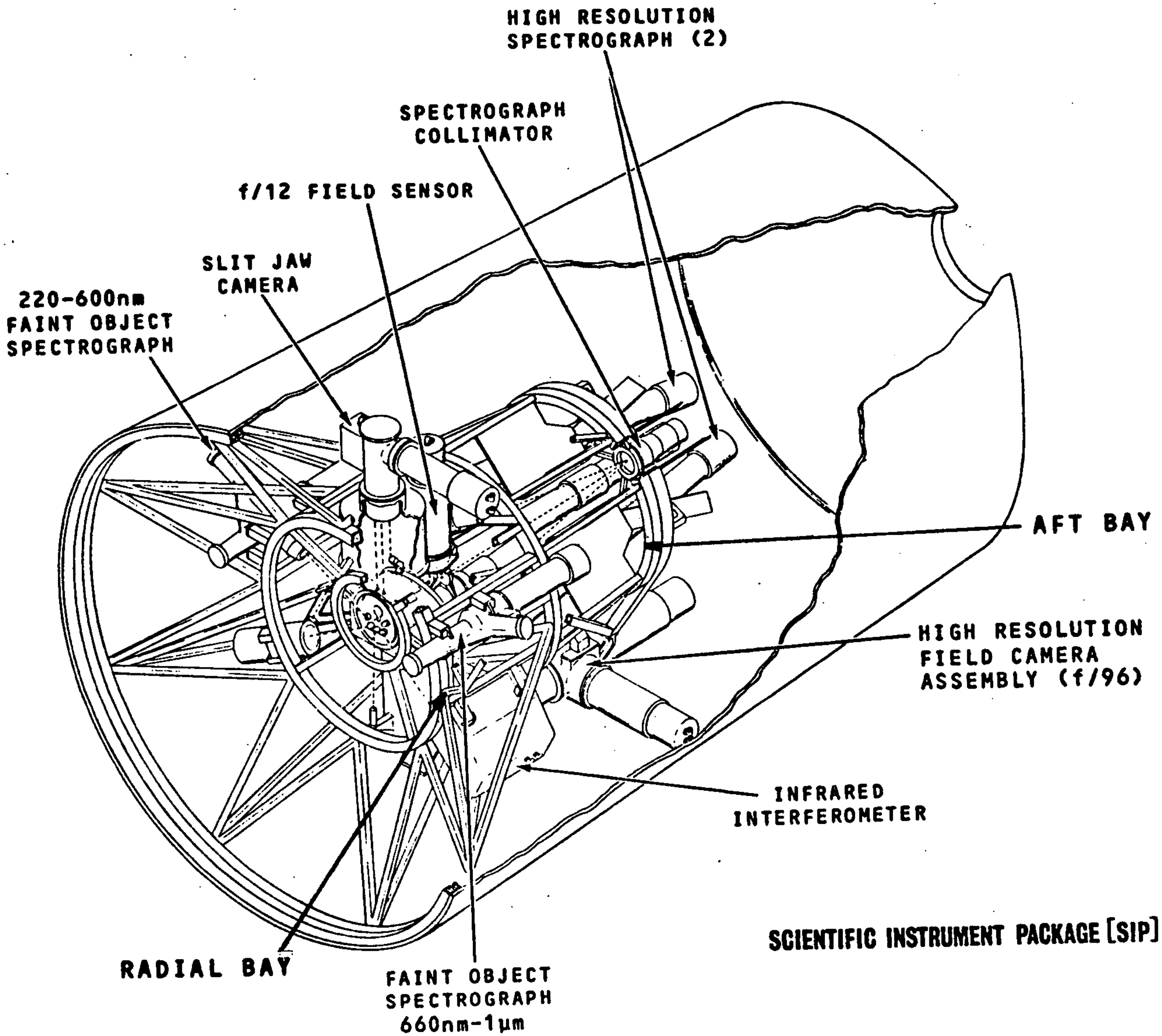



Figure 2-2. SIP Configuration

The energy focused by the OTA is directed to each radial instrument by one of a set of fixed mirrors. The total field of view is divided among the instruments according to instrument priority, accessibility, and the performance requirements of each instrument. Instrument priority, as indicated by the Science Steering Committee, was the primary guide to establishing the off axis (OTA axis) placement of each unit.

The High Resolution Camera is shown as an f/96 system, consistent with the reference SEC-Vidicon Sensor. The optimization is consistent with the high spatial resolution.

The Wide Field Camera uses the direct telescope image (f/12) with the field limited only by the sensor format size. The off-axis location of this camera can be used to accomodate photon counting or higher resolution sensors "yet to be developed", until the off axis aberrations predominate.

## Section 3

## SYSTEM DESIGN CONSIDERATIONS

The major objectives of the Phase A study were to develop design criteria and data for the Scientific Instrument Package, to develop error budgets, and to determine the sensitivity of the design to changes in system parameters. The study also determined the design impact of operational and reliability criteria and of the astronaut's role; furthermore, the effects of future advances in the technological state-of-the-art were considered.

A reference SIP configuration afforded 1. assessment of its impact on the OTA and the SSM, and 2. the establishment of interface specifications. The design development required an analysis of the impact which each of a continuous loop of preliminary decisions had on the many other aspects of the instrument system. Trade-offs included the number and size of the instruments, their priority, cost, efficiency and spectral range.

The following paragraphs describe and graphically summarize some of the major designs and trade-offs.

### INPUTS

The design of the SIP involved the following major technological inputs: type of sensor, photocathode materials, gratings and throughput considerations.

The sensor is one of the major drivers in both camera and spectrograph design. It has a direct effect on the (spectral and spatial) resolution, signal-to-noise ratio and system throughput. It is a major consumer of power and significantly affects the cooling requirements within the SIP. The sensors are among the heavier SIP components.

The sensor selected for the reference design is the SEC Vidicon. This imaging tube has an MTF response of 50% at 20 line-pairs/mm. A maximum integration time of ten hours allows high signal-to-noise ratios, increases sensitivity and eliminates the need for on-board data storage. To meet the Committee requirements, the format of a high resolution camera must accommodate at least $10^8$ (one hundred million) bits of information. As a suitable $10^8$-bit memory is not available for inclusion in the LST, the data storage capability of the SEC Vidicon is an important factor in its selection.

## INSTRUMENT CONFIGURATION SELECTION

The major evaluation parameters for the spectrographs included in the SIP are spectral resolution and spectral throughput. The Faint Object and the High Spectral Resolution Spectrographs requested by the LST steering committee (Table 1) require a total of six separate instruments to cover the spectral bandwidth with the recommended resolution and high spectral response characteristics (efficiency). Each of the following items has a significant influence on the evaluation of these parameters and is summarized in a graph.

### Grating Efficiency

The efficiency of a grating is the percent of monochromatic energy diffracted into a given spectral order. The maximum efficiency occurs at the wavelength for which the grating is blazed. Efficiency variation as a function of wavelength is one of the factors which limits the spectral band the grating may attain. Particularly, the wavelength ratio for a first order grating cannot exceed 1.67 if the blaze efficiency must be larger than 80%. This constraint has a major impact on the Faint Object Spectrographs in which a high efficiency over a broad spectral range is required to detect faint objects. It results in the utilization of three separate instruments and five gratings in the UV-visible range and a separate instrument in the Mid-IR range of the Faint Object Spectrographs.

## Throughput Considerations

The throughput considerations affect the S/N ratio which determines the dimmest object that may be detected by the SIP. The throughput is a function of the wavelength range desired, the optical coatings, the number of reflections, the type of photocathode/window combinations, and the grating(s) dispersion and efficiency.

The throughput analysis uses a zero magnitude star at various black-body temperatures as an input to the LST telescope and computes the output spectral photoelectron density at the sensor photocathode.

The telescope collecting aperture diameter of three meters is used; the clear aperture is determined using a secondary obscuration ration of $\varepsilon = 0.3$.

The 115 nanometer cutoff used for the reference SIP instruments is based on the magnesium fluoride window, which is selected for its long term transmission stability in a space radiation environment. Accordingly, the telescope primary and secondary surfaces and other SIP optical surfaces, where applicable, are optimized for a 115 nanometer wavelength using a predetermined thickness of vacuum deposited aluminum overcoated by the appropriate layer thickness of magnesium fluoride. This coating assures a good efficiency at the reference operating wavelengths and provides growth potential for future capabilities with windowless sensors and for their operating range extension toward lower wavelengths.

Other aluminum optical coating optimizations are used, depending upon the lowest wavelength limitation of the particular optical surface. For optical surfaces which are exposed only to wavelengths above 450 nanometers, a high efficiency silver coating is used.

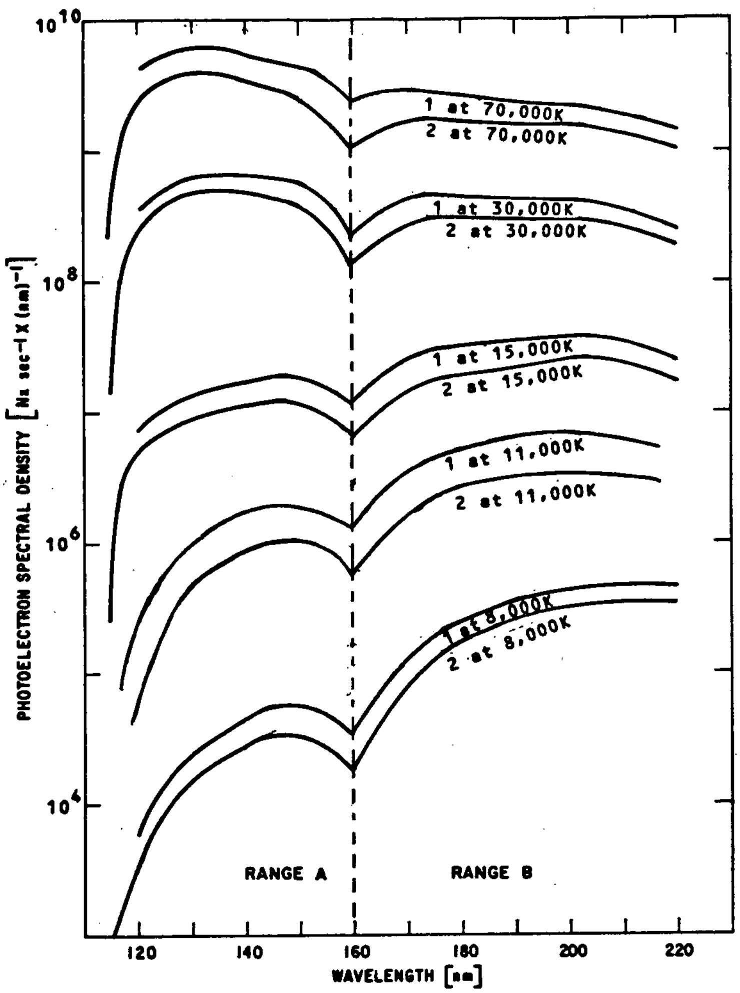
A number of photocathode/window combinations have been reviewed and the ones preselected as the most appropriate, based on their spectral quantum efficiency distribution, are applied to the throughput calculations. Generation of the throughput data is exemplified by the High Resolution Camera (f/96) in Range I (See Figure 3-1.)

A cursory evaluation of the throughput results yields the recognition that although the $CsI/MgF_2$ photocathode offers a higher output peak photoelectron spectral density, the $CsTe/MgF_2$ is preferred in a camera where a broader spectral response corresponds to a higher signal-to-noise ratio in an unfiltered mode.

Using the previously discussed throughput as an input (zero star magnitude), the noise sources, i.e., quantum noise, background noise, photocathode shot noise and preamplifier noise, were used to compute the limiting star magnitude for a S/N ratio of two using the longest signal integration time of $t = 3.6 \times 10^4$ sec (10 hours). In addition, the S/N ratio as a function of star magnitude and integration time was calculated.



B




1) Bialkali/MgF2 (Higher Throughput) 2) $C_sT_e$/MgF2

Figure 3-1. LST High Resolution Camera (f/96) (Range I) Throughput for Zero Mag. Star

Figure 3-2 shows the S/N ratio plot for the High Resolution Camera, Range I. The CsTe photocathode is preferable to the CsI offering a better sensitivity at equal S/N ratio and integration time, or shorter integration time at equal S/N ratio and star magnitude. Thus, the CsTe was selected for Range I of the reference High Resolution Camera.

Similar plots were generated for the other SIP instruments and are useful for prediction of the limiting sensitivity and/or integration time for a given target star magnitude.

DESIGN PARAMETERS

Cameras

The major thrust of the camera design effort was to provide the maximum possible spatial resolution. A high spatial resolution is synonymous with the widest possible MTF response. Figure 3-3 is a plot of some typical MTF's for the SIP camera system. Since

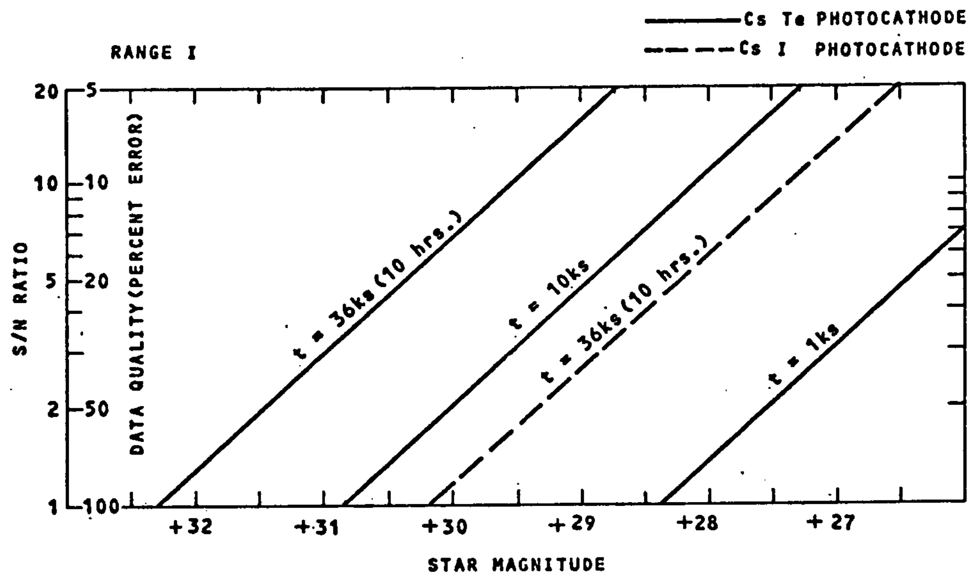



Figure 3-2. High Resolution Camera, Range I, S/N Ratio as a Function of Star Magnitude and Integration Time

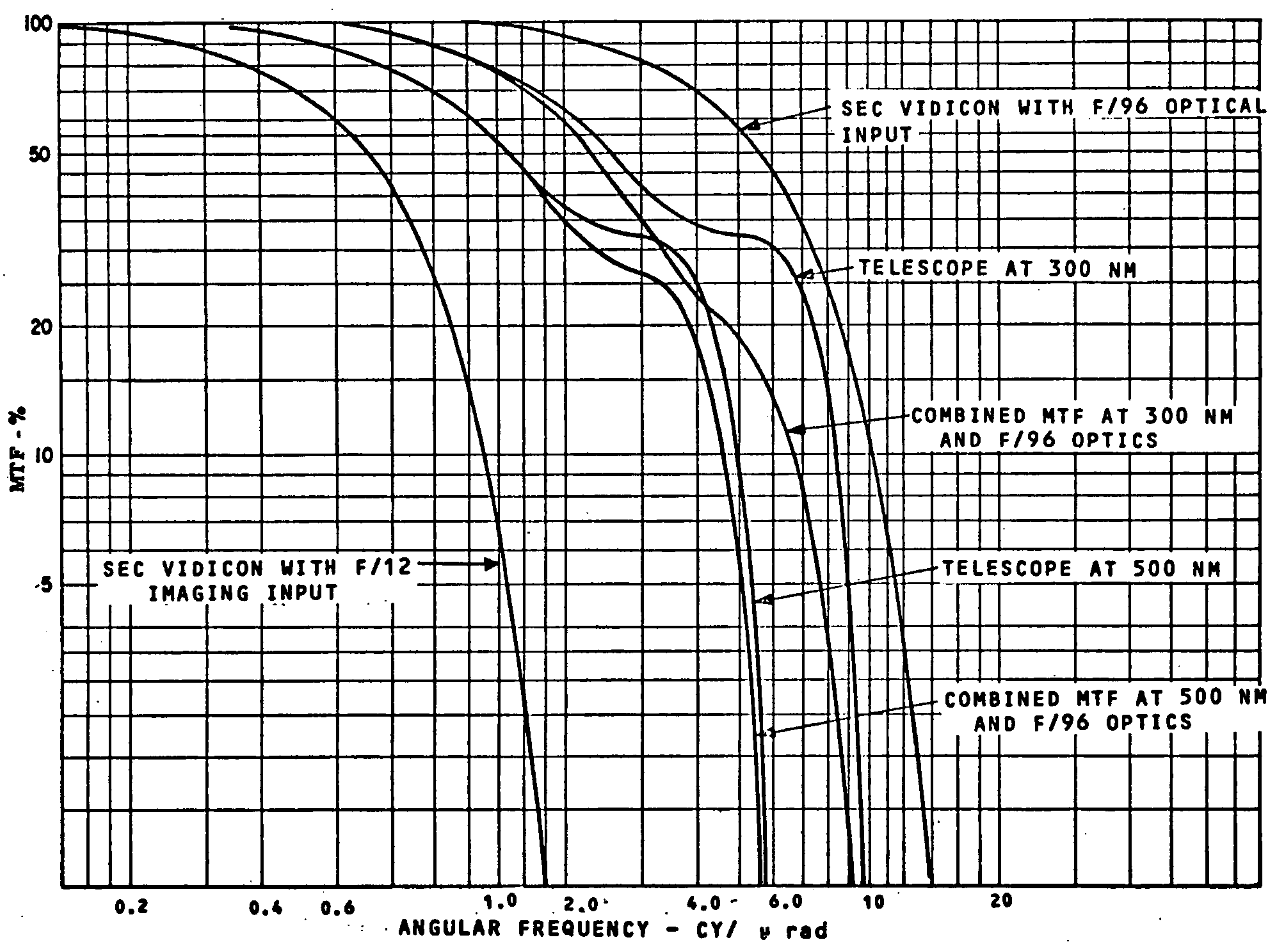



Figure 3-3. High Resolution Camera Performance at 300 nm and 500 nm with SEC Vidicon Detector

the MTF of the telescope cannot exceed the bounds imposed by its diffraction limit, the maximum system MTF is obtained by making the MTF response of the other system elements much broader than that of the telescope. In general, this involves the imposition of tight pointing tolerances and large f numbers. Tight pointing tolerances make the design of the fine guidance difficult and expensive, and large f numbers complicate the design of the optical multiplier. Both of these approaches have an impact on the structural and thermal design.

To determine the f-number and form an error budget which does not impose overly severe restrictions on any subsystem, a study of resolvable element size vs. pointing error was made, using the f number as a parameter. A partial result of the study is shown in Figure 3-4 (Effect of Pointing Instability).

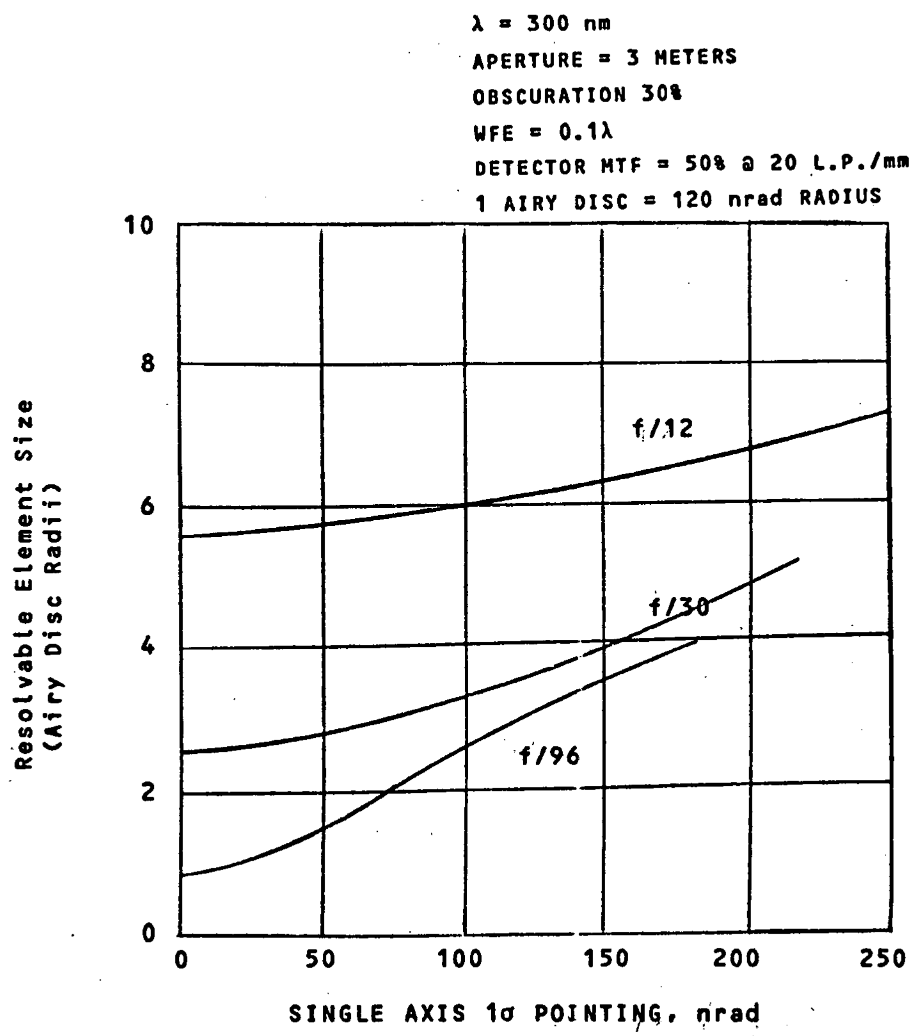



Figure 3-4. Effect of Pointing Instability

As a result of the study, the f-number was chosen as f/96, the pointing instability as 25 nanoradians-1σ, and the telescope wavefront error as 0.1λ. The instrument errors were treated as equivalent pointing errors, specified to be 31 nanoradians. This results in a total equivalent pointing error, which in turn yields a resolution of 1.33 Airy disc radii, which is an increase of 0.33 Airy disc radii over the theoretical diffraction limit. Therefore, the target goals are set at 25 nanoradians 1σ for the telescope pointing, and 31 nanoradians 1σ for the instrument. Neither specification is easily met, and more detailed investigation on the subsystem levels is required. A change in the performance of one subsystem could effect the specifications placed on another. As an example, if the structural and thermal phenomena preclude an instrument error of less than 50 nanoradians, then the specification for the pointing would be loosened unless it was apparent that 25 nanoradians 1σ pointing is easily achievable. The reason for this is that the total error would then be $\sqrt{50^2 + 25^2}$ or 55 nanoradians. To allot 50 out of 55 nanoradians to the instrument is unrealistic. Under this condition, if the pointing error were specified as 40 nanoradians, the total error would be 64 nanoradians, or an increase of 30% over the instrument error, and the resolvable image size would be 1.83 Airy discs.

From the above example, it can be seen that changes in the state-of-the-art should be monitored for information pertaining to the desired use of the instrument by the astronomers. It is our opinion that further trade-off studies in this area would be most useful to both the engineering and scientific community.

If the telescope image degrades due to some unpredictable phenomena then the random errors tend to increase the image size. This increase in image size may be treated as "equivalent pointing instability" and root sum squared with the pointing error to predict resolution. Figure 3-4 shows the effect of image growth in nanoradians on spatial resolution in Airy disc radii.

### Spectrographs

The spectrographs were designed for two applications: high resolution of brighter objects, and lower resolution on the dimmest objects possible.

### Spectrograph Formats

A single line spectrograph with a spectral resolution of $\lambda/\Delta\lambda = 3 \times 10^4$ would require an image format over three meters in length. This is impractical for many reasons which cannot be detailed here. A high order echelle configuration is used for the

high resolution spectrograph because its spectrum can be displayed as a coarse raster and matched to the TV sensor's linear resolution and format size. A second grating, which operates in the first order, separates overlapping orders.

The relatively low spectral resolution of the Faint Object Spectrograph does not lend itself to the multi order format display. All of the Faint Object Spectrographs operate in first order on single line display and are limited by tube format size among other restrictions. The spectrograph formats are shown in Figures 3-5 and 3-6.

The spectrographs are analyzed to determine which optimum wavelength sub-ranges cover the desired spectrum. After the wavelengths have been optimized, parametric studies determine the remaining variables by selecting, from the family of solutions, the one which maximizes the overall tolerance for the instrument. The results of a typical study are shown in Figure 3-7.

Effect of Telescope Image Size on Spectrograph Resolution

The spectrograph resolution is relatively insensitive to changes in telescope image size as shown in Figure 3-8. A change of 100% in telescope image size results in a decrease of only 10% in spectrograph resolution. This assumes the telescope image is always smaller than the entrance slit width.

For a given dispersion, the spectrograph resolution is determined by the size of the total image blur at the sensor. The blur size chosen for the LST designs was the width of a sensor line pair, 50 μmeters.

The telescope image blur can be 0.44 μradians and meet the requirements of the spectrographs. As the spectrographs are f/10 to f/12 designs, the size of the telescope image at the sensor is about 12 μmeters. The total blur is the root sum square of the blurs due to the telescope and spectrograph. The telescope blur is about one-fourth of the total, therefore, a large telescope image deterioration causes only a small loss in resolution.

If the image initially fills the slit width, $W_1$, and then grows, the resolution will not decrease because the image "width" is determined by the entrance slit. But the S/N ratio will decrease because less energy will reach the detector. Figure 3-9 shows the S/N ratio as a function of image growth for this condition.

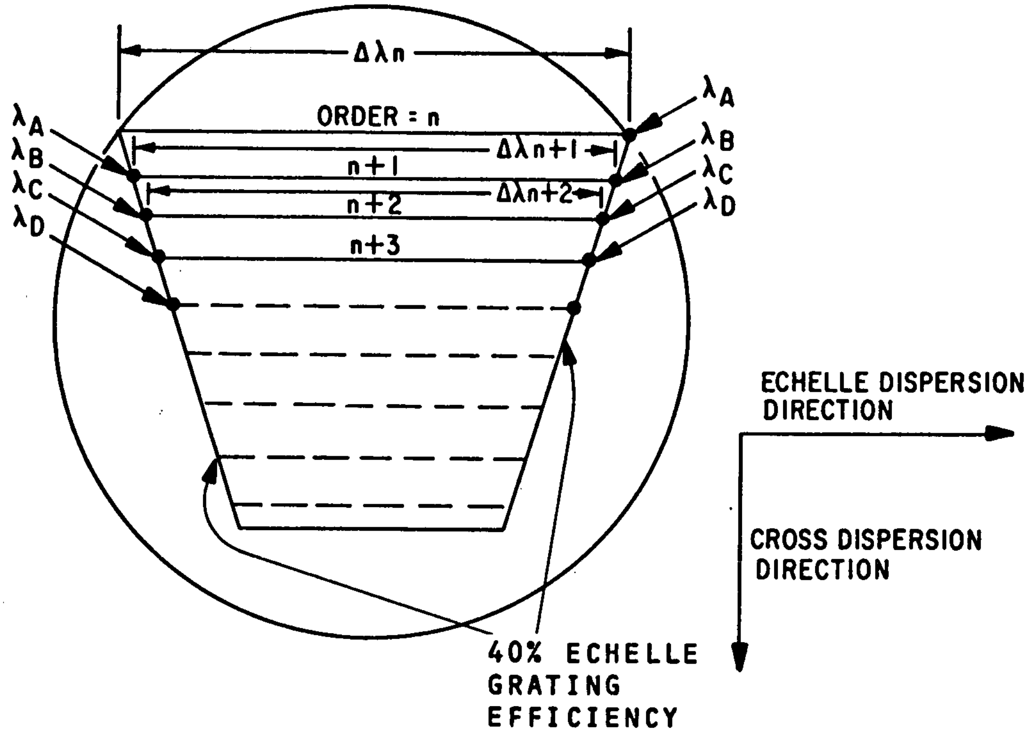



Figure 3-5. Spectrograph Format, Area Presentation (Echelle)

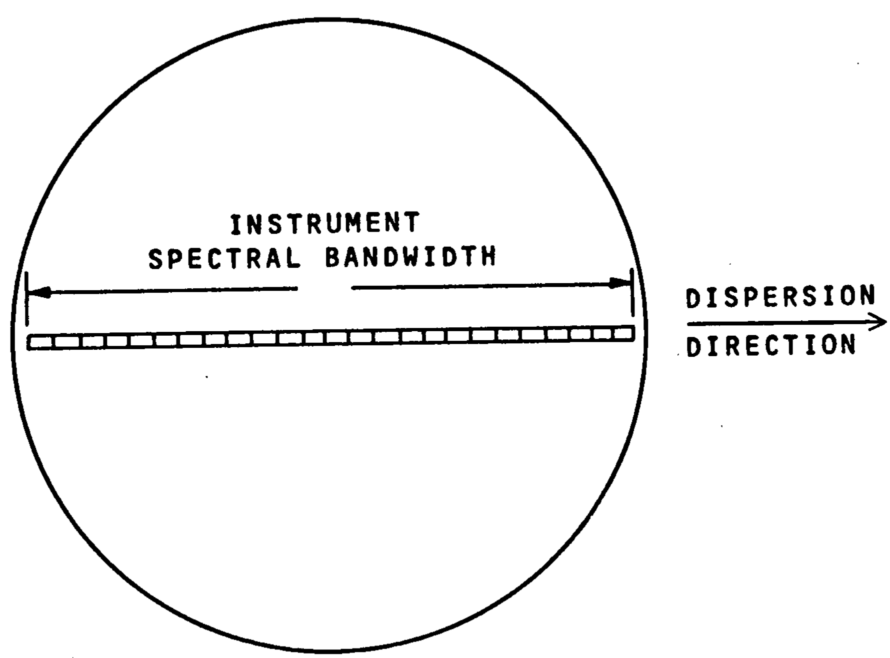



Figure 3-6. Spectrograph Format, Line Presentation

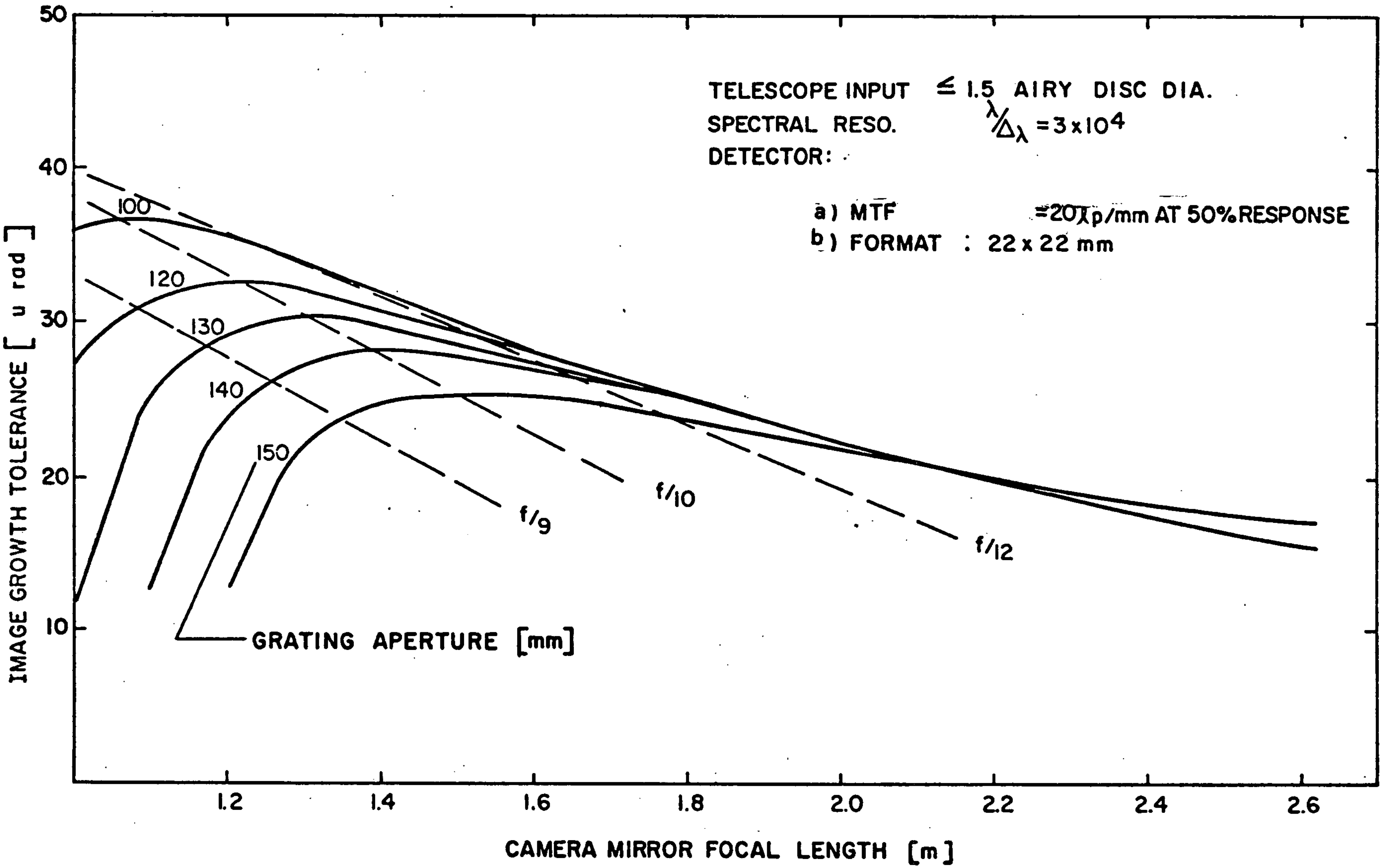



Figure 3-7. High Resolution Spectrograph, Error Budget for 180<λ<350 nm

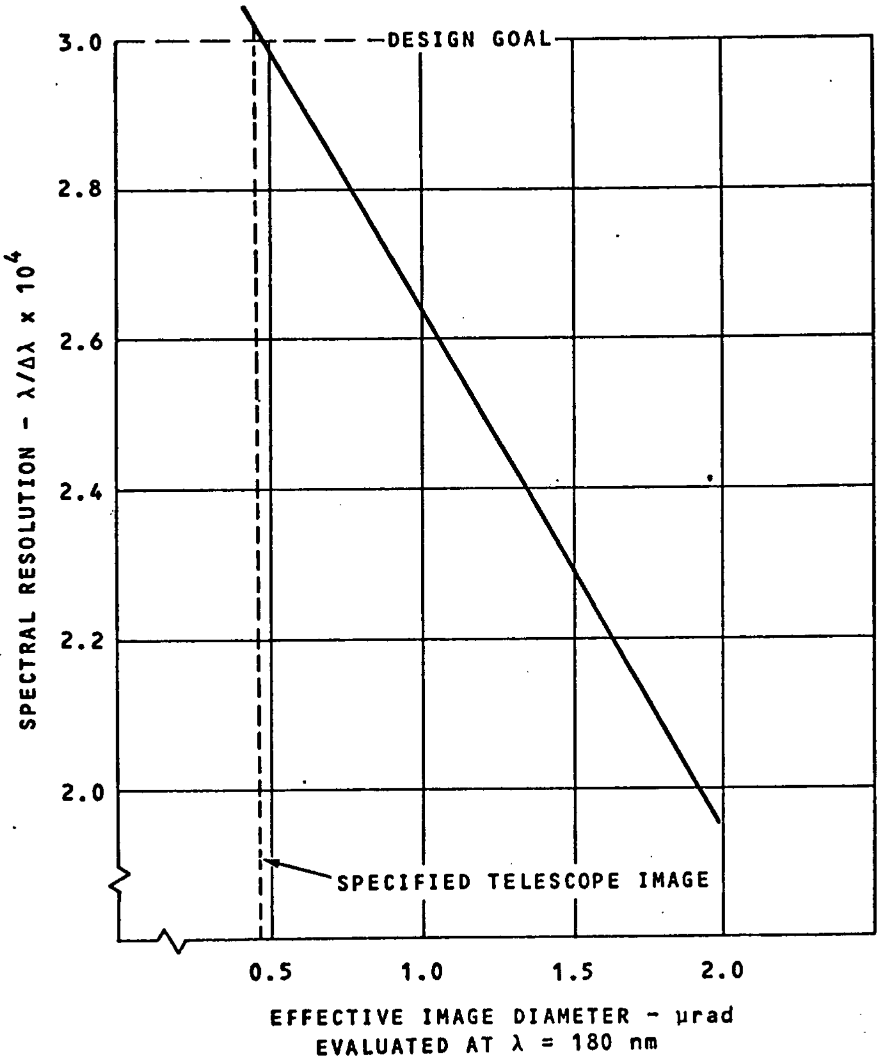



Figure 3-8. Effect of Telescope Image on Spectral Resolution of High Resolution Spectrograph II

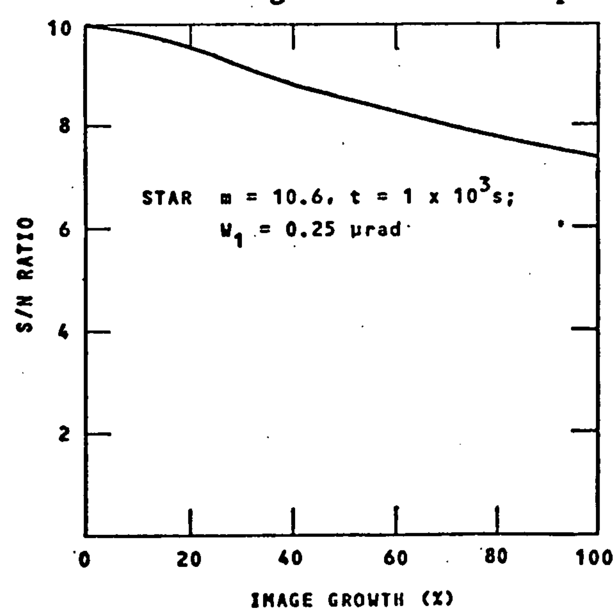



Figure 3-9. S/N as a Function of Image Size

## SYSTEM OPERATIONAL HARDWARE AND RELIABILITY CONSIDERATIONS

The main driving factors are (1) the role of the astronaut and the implications of that role, and (2) the problems of data handling, which are somewhat affected by the role of the astronaut.

Other than checking for loss of power and broken cables, and performing visual inspections, the astronaut is not expected to function as a troubleshooter. Such a role implies that the major troubleshooting will be performed on the ground. This leads to the design of a system which requires considerable monitoring because the approach (1) maximizes the possibility of pinpointing the causes of failure, (2) minimizes the possibility of a false indication in the monitoring system causing a needless replacement, and (3) is useful in determining if a gradual deterioration is taking place in any instrument. The housekeeping or monitoring data is transmitted in its entirety. The number of housekeeping bits is about 2000 for all of the instruments, which is small compared to the $8 \times 10^7$ bits of a 50 mm SEC-vidicon. This data is necessary to check on any gradual deterioration. If such data is on file, it can be referred to for evaluation.

## EFFECT OF IMPROVED SENSORS ON INSTRUMENT PERFORMANCE

Since the sensor is one of the major drivers in the SIP design, it is important to consider the effect on system design and performance of improved sensor performance. Improvements could come in the form of decreased focus coil power, presently 25 watts, an increase in target gain, an increase in target capacity in terms of photoelectrons at saturation, an increase in linear resolution, and a decrease in tube noise.

A decrease in focus coil power will simplify the cooling and power supply problems. An increase in target gain will diminish the effect of preamplifier noise, enabling the spectrographs to more closely approach the background noise limit. An increase in target capacity will improve the S/N ratio during a single scan by (1) decreasing the "noise" in the signal, s, which = $1/\sqrt{s}$, and (2) increasing the ratio of the signal to amplifier noise.

The effect of an increase in resolution may be deduced by observing the curves in Figures 3-3 and 3-4. If the general shape of the MTF curve ($e^{-b^2w^2}$) remains the same while the limiting frequency increases, then the effect on instrument resolution caused by that increase is identical to a corresponding change in f/number. For example, if the sensor's limiting frequency doubled, an f/48 system would yield the same resolution as the present f/96. The use of an f/48 system would simplify the thermal, structural, and the mechanical problems associated with the high resolution camera and the optical multiplier, and would result in a smaller package size yielding an increase in the field of view. A decrease in tube noise would permit the viewing of dimmer objects with the spectrographs, which at present are sensor and preamplifier noise limited.

# Section 4

# INSTRUMENT CONFIGURATION

The instruments described in the following paragraphs were developed to provide a reference system that would satisfy preliminary scientific requirements, the program performance objectives, and take full advantage of the state-of-the-art of various technologies in the 1970's.

Instrument design was performed by treating the SIP as an integrated system, and performing tradeoff studies and configuration evaluations until a satisfactory layout of the instrument complement was achieved. The designs are not "sharply tuned", but will allow design modification to fit a considerable range of operational parameters when these are better defined.

The performance summary of these instruments are shown in Tables 4-1, 4-2 and 4-3.

## 4.1 WIDE FIELD CAMERA (f/12)

The Wide Field Camera is at the Cassegrain focus of the telescope and receives its light after three reflections (See Figure 4-1.) It covers a field of 1.4 mrad (4.8 arc min.).

The central portion of the telescope field is used for the High Resolution Camera and several spectrographic instruments. A diagonal mirror located above the axis folds a portion of the Ritchey-Chretien field-of-view to a TV tube located in a radial bay. The center of the camera's 50 x 50 mm format (1.4 x 1.4 mrad field-of-view) is located 2 mrad (6.7 arc min.) off axis. At this field angle, the astigmatism of the Ritchey-Chretien becomes troublesome. On a flat focal plane the imagery would be seriously degraded. In this case, the tube is tilted and focused between the sagittal and tangential foci. This yields acceptable imagery for the f/12 camera.

## 4.2 HIGH SPATIAL RESOLUTION CAMERA ASSEMBLY

The High Resolution Camera is contained in a cross-shaped housing mounted outboard of the SIP structure. Its optical input

TABLE 4-1

FIELD CAMERAS

| Camera (f/No.) | Equivalent Focal Length Meters | Plate Scale μrad/mm | Reciprocal Plate/Scale μm/μrad (μm/Arc Sec) | Field of View mrad | Limiting Resolution nrad (< 27 mag λ = 300 nm) | Limiting Magnitude $m_v$ (S/N = 2) |
|---|---|---|---|---|---|---|
| Wide Field (f/12) | 36 | 27.8 | 36 (175) | 1.39 | 840 | 30.5 |
| High Resolution (f/96) | 288 | 3.48 | 288 (1400) | 0.173 | 160 | 32.5 |

TABLE 4-2

HIGH SPECTRAL RESOLUTION SPECTROGRAPHS

| Instrument | Spectral Range $\lambda_1$-$\lambda_2$ (nm) | Dispersion at $\lambda_1$ nm/mm | Plate Scale μrad/mm | Spectral Resolution $\lambda_1/\Delta\lambda$ | Limiting Magnitude $m_v$ (S/N = 2) |
|---|---|---|---|---|---|
| High Spectral Resolution Spectrograph I | 110*-180 | 0.06 | 33.2 | $4.5 \times 10^4$ | 17.2 |
| High Spectral Resolution Spectrograph II | 180 -350 | 0.12 | 33.2 | $3.0 \times 10^4$ | 19.7 |

* Sensor window material requires $\lambda_1$ >115 nm

TABLE 4-3

FAINT OBJECT SPECTROGRAPHS

| Instrument | Spectral Range $\lambda_1$-$\lambda_2$(nm) | Dispersion at $\lambda_1$ nm/mm | Plate Scale μrad/mm | Spectral Resolution $\lambda_1/\Delta\lambda$ | Limiting Magnitude $m_v$ (S/N = 2) |
|---|---|---|---|---|---|
| Faint Object Spectrograph I | A 110* - 160 | 1.67 | 37.0 | $1.25 \times 10^3$ | 21 |
| | B 160 - 220 | 2.00 | 37.0 | $1.75 \times 10^3$ | 22.5 |
| Faint Object Spectrograph II | A 220 - 350 | 4.40 | 27.3 | $1.23 \times 10^3$ | 25 |
| | B 350 - 660 | 10.27 | 27.3 | $0.75 \times 10^3$ | 25 |
| Faint Object Spectrograph III | 660 - 1000 | 11.33 | 27.3 | $1.5 \times 10^3$ | 22 |
| Mid-IR Interferometer | 1 - 5μm | NA | NA | NA | 13 |

* Sensor window material requires $\lambda_1$ >115 nm

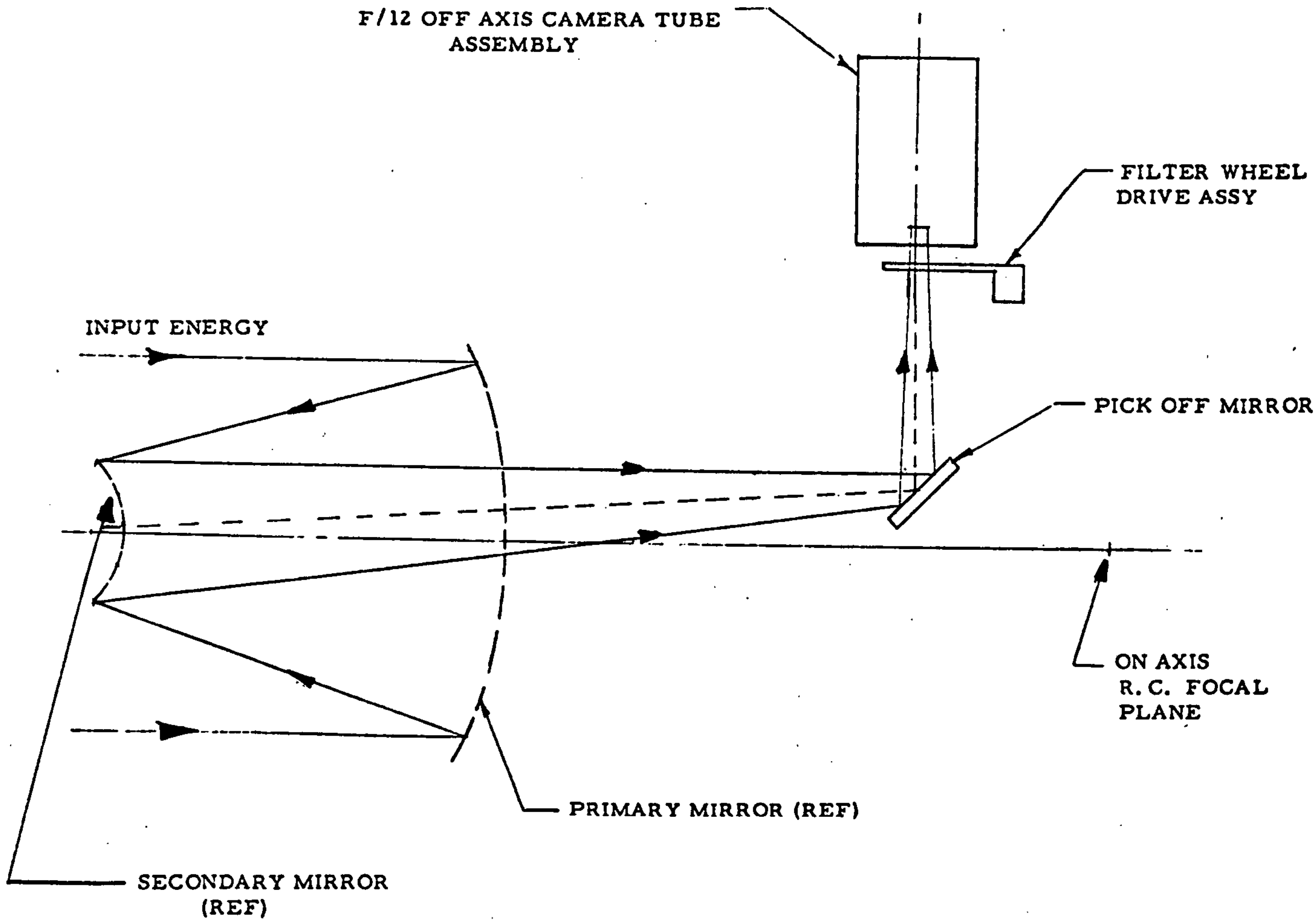



Figure 4-1. Wide Field Camera Functional Schematic

is the f/12 bundle, and is re-imaged by the 8X camera optics to a focal plane at the selected sensor's cathode as shown in Figure 4-2. The 50 x 50 mm cathode image format produces a field of view of 174 x 174 μrad in object space.

The camera contains three sensors from which the experimenter can choose for response in a particular spectral range of interest or, by successive observations, to explore the total available spectral range. The spectral bands or ranges are as follows:

Range I - 115- 300 nm

Range II - 160- 600 nm

Range III - 500-1100 nm

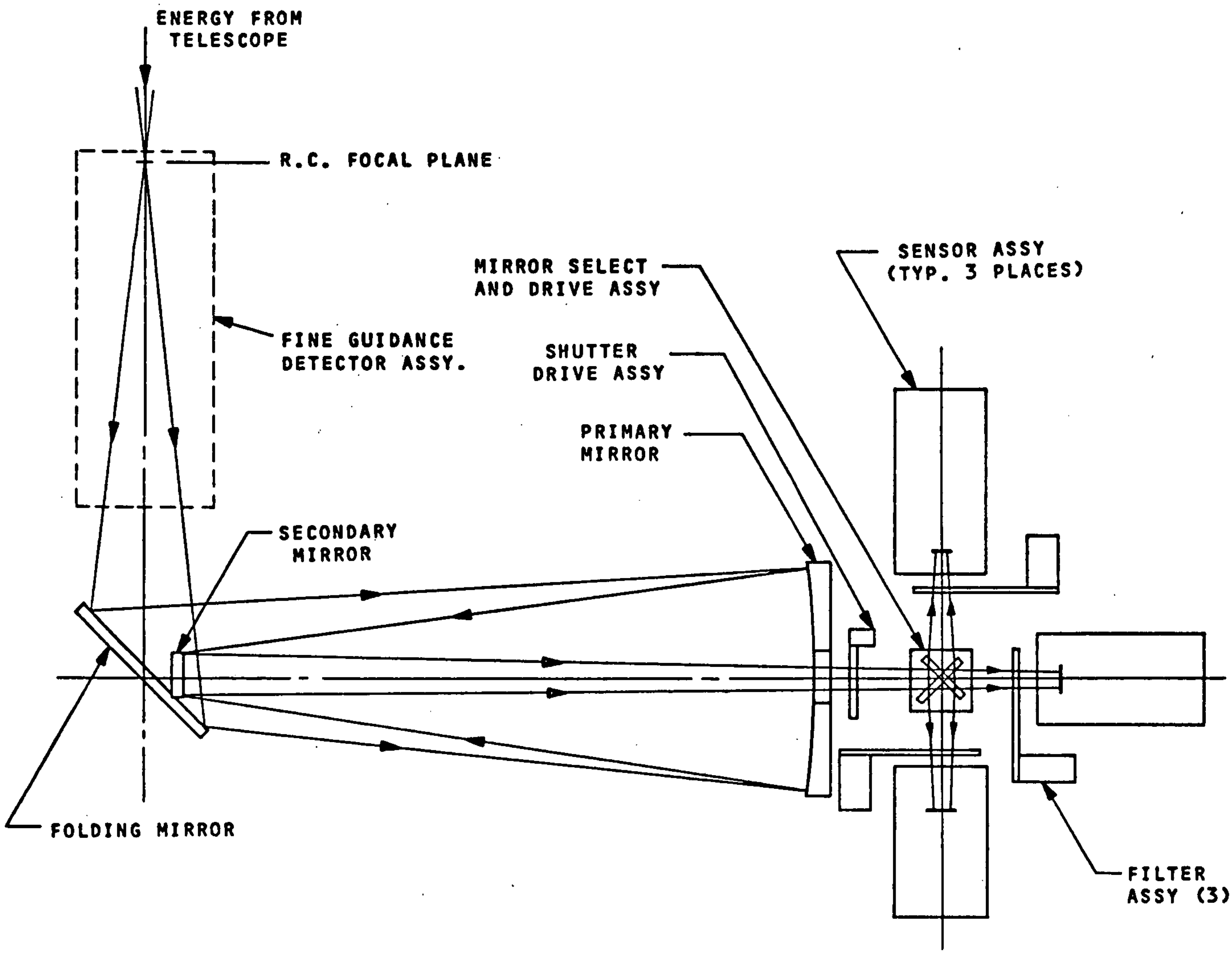



Figure 4-2. High Resolution Camera Functional Schematic

Each of the three sensors is provided with a filter select mechanism which permits the inclusion of up to four spectral filters. The positioning of the high resolution camera energy bundles on the desired sensor's cathode is controlled by a Mirror Select and Drive Assembly. A shutter capable of occulting the energy entering the sensor area is provided to protect the sensors and to permit measurement of sensor dark noise.

The high resolution camera is intended to achieve the full resolution capability of the OTA over the spectral range of 115 to 1100 nm. Further desirable properties of this instrument are:

1. Maximum field of view consistent with 50 mm sensor

2. Minimum number of reflections (ultra violet efficiency).

3. Compact as possible.

The broad spectral band demands that a reflective system be used. The reference system is a two mirror inverse Cassegrain that serves both to relay the f/12 image of the Ritchey-Chretien and to magnify it eight times, forming an f/96 image on the face of a 50 x 50 mm camera tube sensor.

The high resolution system has been given the highest priority among the LST instruments, and has therefore been kept on axis with respect to the telescope. The optical design provides a camera that is essentially diffraction limited, and there is no vignetting out to the edge of the sensor.

## 4.3 HIGH RESOLUTION SPECTROGRAPHS

The High Resolution Spectrograph consists of two nearly identical instruments, one which covers the spectral range from 110 to 180 nm, and one which covers the spectral range from 180 to 350 nm. The major differences in the instruments are the grating ruling frequencies and the photocathodes of the detectors. Referring to Figure 4-3, the input is the f/12 energy bundle which passes through the entrance slit to the off-axis paraboloid which collimates the light and directs it to the echelle grating. The cross disperser spearates orders in the echelle spectrum. The camera mirror, operating at f/10, focuses the doubly dispersed bundle through a hole in the cross disperser onto a 25 mm sensor photocathode. It is essential to have the camera mirror operate on axis, for coma and astigmatism of the spherical mirror increase very rapidly with the field angle.

Instrument selection is accomplished by first offsetting the LST so that the object of interest passes through the slit, then rotating the off-axis collimator about the telescope axis to the position which directs the light to the selected echelle grating.

The efficiency of an echelle and cross disperser combination causes an energy loss that increases rapidly with spectral bandwidth. It is for this reason that the spectral range of 115 to 350 nm is divided between two instruments. The spectral and angular resolution for each instrument is consistent with the 50 μm length of a detector resolution cycle (two TV lines) at 50% MTF.

Ray traces at various wavelengths have shown that the image will be contained in a circle of approximately 0.025 mm in diameter. This is sufficiently smaller than the 0.05 mm line spacing to permit variations due to temperature and angular motions during the exposure time.

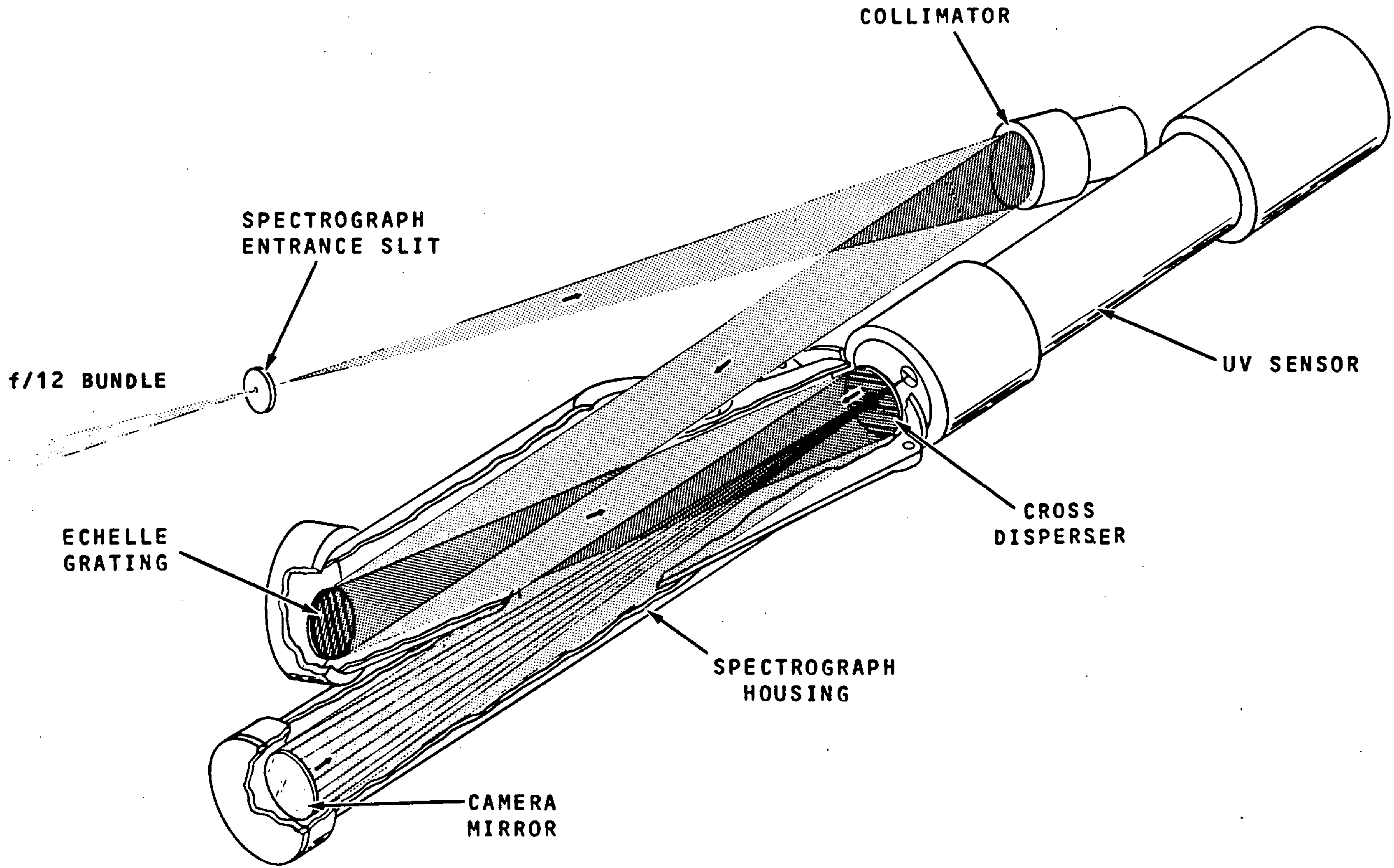



Figure 4-3. High Resolution Spectrograph

4.4 FAINT OBJECT SPECTROGRAPH

The faint object spectrograph, with a resolving power of $10^3$, covers the spectral range from 115 nm to 5 μm with four instruments. The first is a single dispersion instrument which covers the range from 115-220 nm using two interchangeable reflective gratings to break the spectrum into two intervals; 115 to 160 nm and 160-220 nm.

Figure 4-4 is an optical schematic of the instrument which measures each of the two spectral intervals. One interval is used at a time. The sensor, a SEC Vidicon, provides spectral coverage commensurate with the total range. The instrument output is a line image 30 mm long, for which the small sensor type provides a sufficient photocathode diameter.

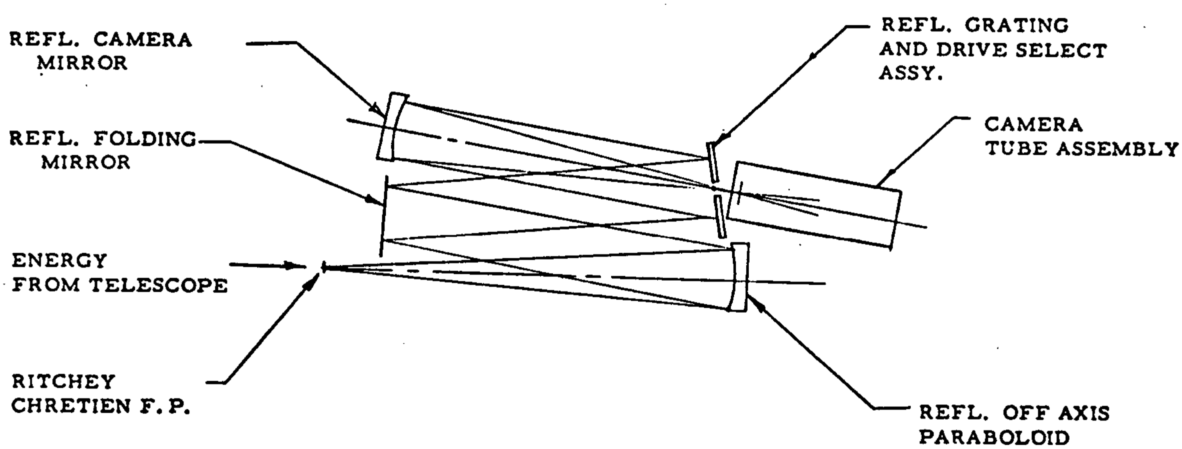



Figure 4-4. Faint Object Spectrograph 115-160 nm (1A)
Functional Schematic 160-220 nm (1B)

The second instrument, also a single dispersion type provides spectral coverage of the 220-660 nm range and is shown in Figure 4-5. A beamsplitter follows the collimator and the reflected and transmitted energy bundles impinge on two separate Wadsworth gratings which are optimized for two wavelengths and provide two parallel spectra renditions (30 mm long) on a single sensor for two ranges: 220-350 and 350-660 nm.

The third instrument provides a spectral coverage in the 660-1000 nm range. The instrument has essentially the same configuration as Faint Object Spectrograph number 2, but without the dichroic beamsplitter.

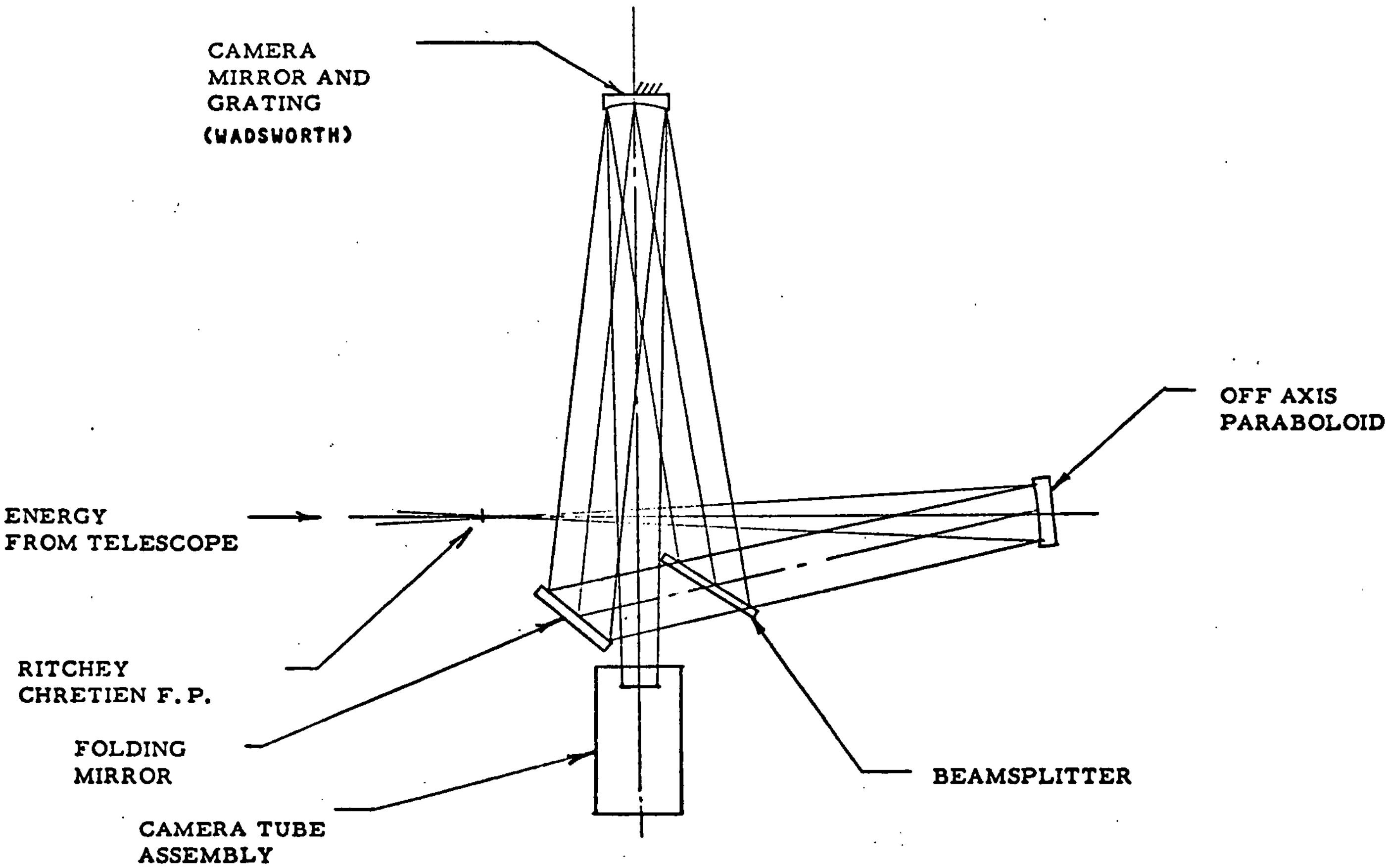



Figure 4-5. Faint Object Spectrograph #2 220-350 nm
Functional Schematic 350-660 nm

For the wide spectral range of 1-5 μm, a high data rate is obtained using a modified Fourier interferometer. The interferometer optical schematic is shown in Figure 4-6, in which a solid state detector is indicated. Implementation of a reference (black body), a mirror position monitor, the laser and PMT detector, are shown in the associated foreoptics (Figure 4-7).

The high instrument data rate requires an on-board storage and computerized ground processing of the interferograms.

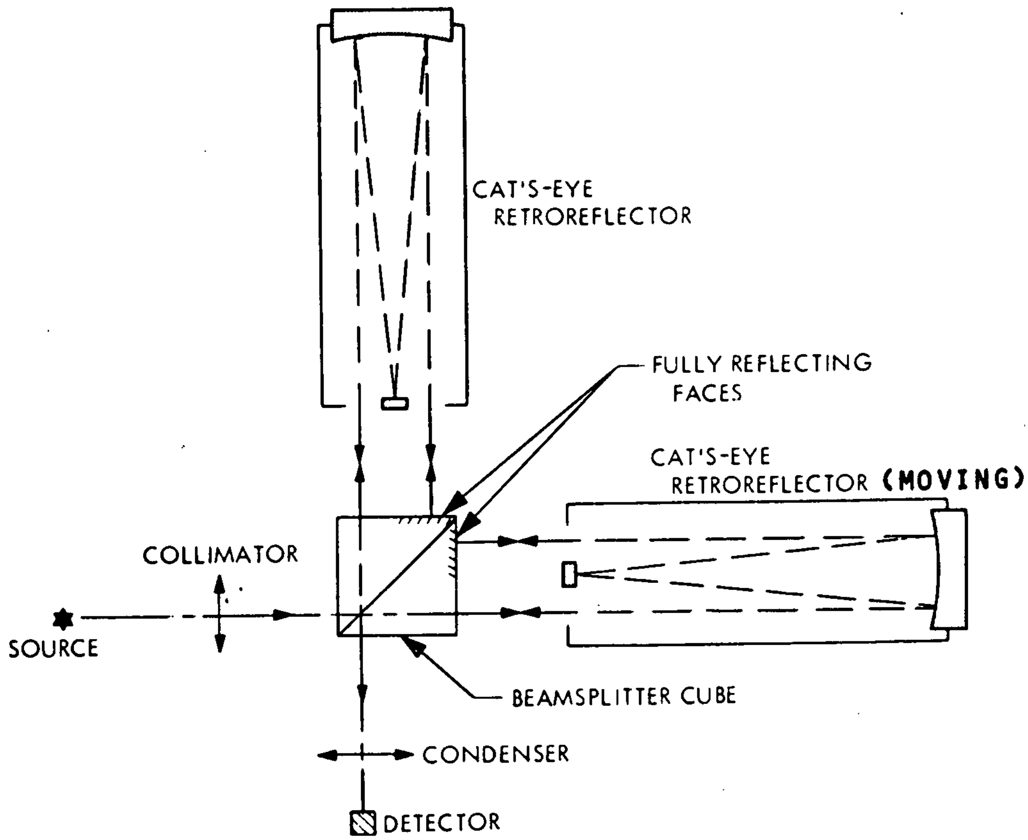



Figure 4-6. Functional Schematic Interferometer (Faint Object Spectrograph Number 4)

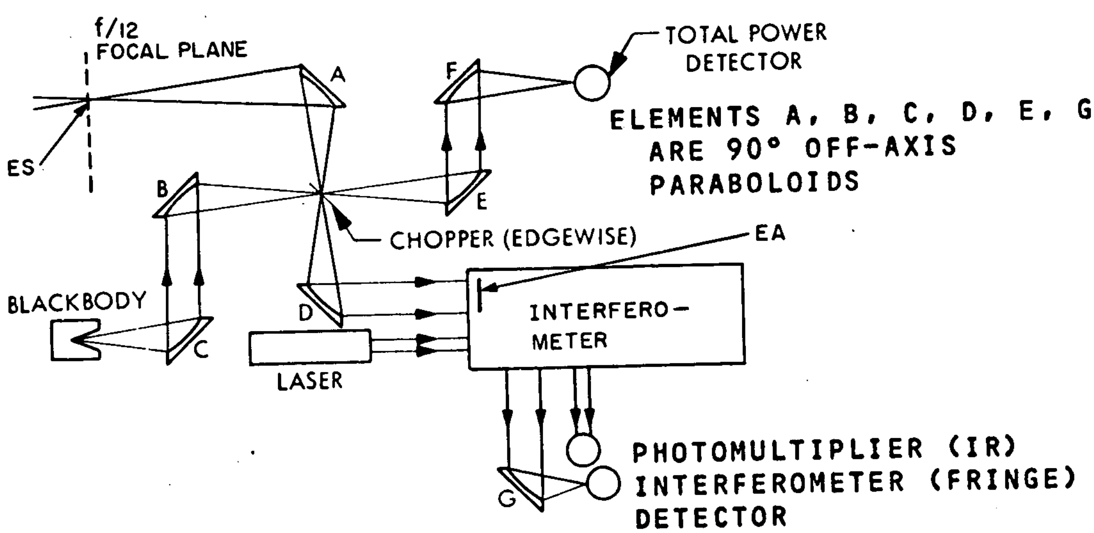



Figure 4-7. Foreoptics of Interferometer (Faint Object Spectrograph Number 4)

# Section 5

# REFERENCE DESIGN SUMMARY

## 5.1 WEIGHT

The calculated weight estimates for the SIP hardware are summarized in Table 5-1. These estimates are based on use of aluminum housings for the instruments and graphite epoxy for the secondary instrument support structure.

TABLE 5-1

SIP WEIGHT ESTIMATE

| | Lb. | Kg. |
|---|---|---|
| Wide Field Camera (f/12) | 157 | 71 |
| High Resolution Camera (f/96) | 526 | 239 |
| High Resolution Spectrographs (2) | 275 | 125 |
| Faint Object Spectrographs (4) | 466 | 211 |
| Slit Jaw Camera | 105 | 48 |
| Mechanisms | 28 | 12 |
| Cables and Miscellaneous | 79 | 36 |
| Secondary Support Structure | 418 | 189 |
| TOTAL | 2,054 | 931 |

## 5.2 POWER

The power consumed by the SIP is a function of the number of devices that are operational at a given time and is a function of the status of the instrument. The total power drawn will vary with the use sequence, observation time and warm-up time required for each sensor. For instance, if the warm-up time for a sensor is considerably longer than the observation time, two or more sensors will be powered simultaneously. Since there is no a priori knowledge of what the "average" sequence will be, it is difficult to arrive at an "average" power consumption. Instead, two indications will be given; the per instrument power summary of Table 5-2, and "typical" operating sequence power consumptions.

TABLE 5-2

POWER REQUIREMENT ESTIMATES

| | |
|---|---|
| Wide Field Camera (f/12) | 36 watts |
| High Resolution Camera (f/96), 3 detectors | 37 watts each |
| High Resolution Spectrographs (2) | 16 watts each |
| Faint Object Spectrographs (4) | 27 watts each |
| Slit Jaw Camera | 16 watts |
| Aft Spectrograph Slit Drive | 4 watts |
| Spectrograph Selector | 3 watts |

"Typical" operating sequences are shown in Figure 5-1. Case I is for a three hour observation using the High Resolution (50 mm Vidicon) Camera, and a five hour observation using the High Resolution Spectrograph (25 mm Vidicon). Case II is for three successive 45 minute exposures using a 25 mm SEC Vidicon, and Case III is for three successive 45 minute exposures using a 50 mm Vidicon. The assumptions upon which the profiles are based are:

1. The tubes require a two hour warm-up.

2. Occultation occurs from 0.75 to 1.5 hr., 2.25 to 3 hr., etc.

3. At time t = -2 hr., the first tube focus coil is energized, and the power consumption exclusive of the tube is 20 watts due to:

   a. 10 watts for 10 tube cathode heaters.

   b. 5 watts for all mechanisms.

   c. 5 watts standby power for unused instruments.

4. Peltier coolers (one possible method, requires 50 watts to cool the cathode of a 50 mm Vidicon) are not needed.

At t = -2 hours, the power consumption is equal to the power consumed by the tube plus 20 watts. For Case I, the power at t - -2 hours is 52 watts; for CAse II, 34 watts, and for Case III, 52 watts.

If a dim target is being observed, then coolers must be used, and 50 watts of additional power per 50 mm tube and 25 watts per 25 mm tube is consumed. This would cause a peak power of 66 watts for Case I, 76 watts for Case II, and 158 watts for Case III.

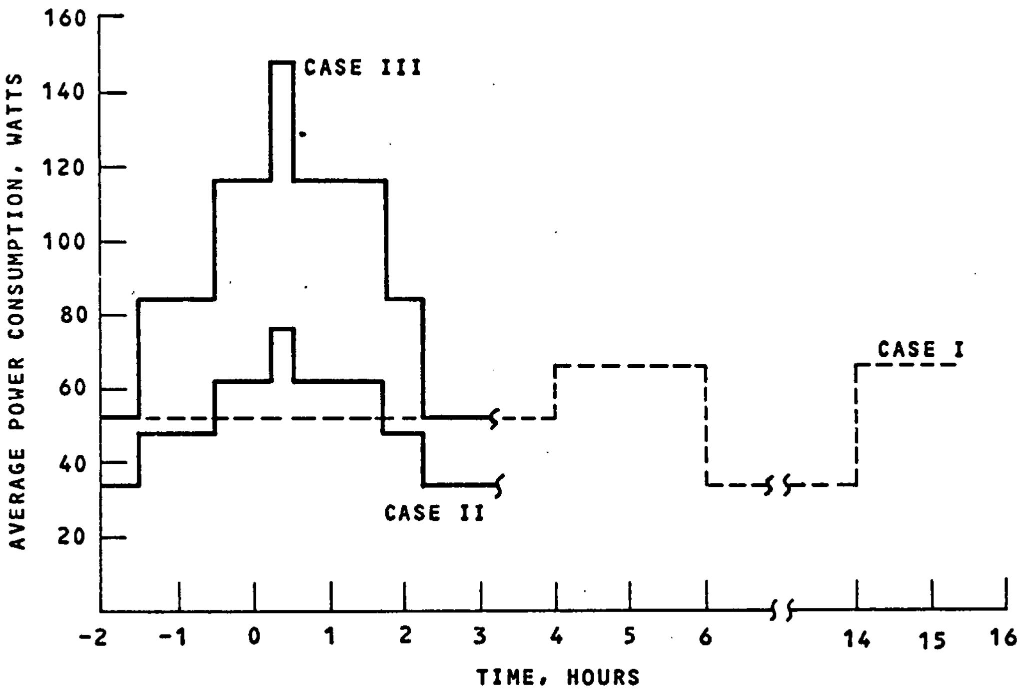



Figure 5-1. Power Profile Examples

## 5.3 DATA

Table 5-3 is a summary of the SIP data requirements estimate. The calculations are based on a 20 line pair per millimeter resolution, sampling at twice the Nyquist frequency, a transmission rate of $10^6$ bits/second, and a height of 1 mm for the line presentation formats. The status data includes provisions for pre-experiment checks, secondary data to improve the accuracy of the scientific data and performance monitoring and troubleshooting data.

TABLE 5-3

DATA ESTIMATE SUMMARY

| | Scientific Data Bits | Input Command Bits | Status Data Bits |
|---|---|---|---|
| Wide Field Camera (f/12) | $8 \times 10^7$ | 223 | 190 |
| High Resolution Camera (f/96), Three Detectors | $8 \times 10^7$ each detector | 230 each | 200 each |
| High Resolution Spectrographs (2) | $2 \times 10^7$ each | 215 each | 122 each |
| Faint Object Spectrographs (3) | $8 \times 10^5$ or $16 \times 10^5$ each | 223 each | 189 each |

TABLE 5-3

DATA ESTIMATE SUMMARY (Cont.)

| | Scientific Data Bits | Input Command Bits | Status Data Bits |
|---|---|---|---|
| Mid-IR Interferometer | $2 \times 10^6$ | 272 | 205 |
| Slit Jaw Camera | $2 \times 10^7$ | 121 | 69 |
| Aft Spectrograph Slit Drive | - | 108 | 79 |
| Spectrograph Selector | - | 103 | 79 |
| Calibration Sources | - | 10 | 10 |

# SECTION 6

## STUDY SUMMARY AND RECOMMENDATIONS

This study has shown that it is feasible to design and build a Scientific Instrument Package for the LST capable of near diffraction limited imagery and high spectral resolution. The instrument can be used for several decades and is capable of growth and modification in accordance with the requirements of advancing technology. This general purpose instrument can be available to the astronomy community by 1980.

The recommendations that are recommended for the next phase of the LST-SIP development are summarized as follows:

1. For the assumptions which were used in this study, there exists a family of non-critical instrument design concepts:

   a. An f/96 design for the high resolution camera and an f/12 design for the wide field camera.

   b. An f/9 to f/12 range for the spectrographs. An area presentation should be used for the high resolution spectrograph applications. A line presentation should be used for the low resolution spectrograph applications.

   c. A memory is required for the Mid-IR Faint Object Spectrograph (1-5 micrometer).

2. Two assumptions which have significant impact on the design are that (1) the camera tube resolution is 20 lp/mm and (2) the minimum allowable first order grating efficiency is 80%. If the tube development yields a superior resolution, e.g., 60 lp/mm, the high resolution camera f/number can be reduced to 32 and higher spectral resolution can be achieved by the spectrographs. If the allowable grating efficiency is reduced, fewer gratings will be needed for the spectrographs.

3. Some LST parameters have much greater impact on one type of instrument than another, i.e., the High Resolution Camera determines the LST pointing stability requirements. The High Resolution Spectrographs determine the LST pointing accuracy requirements.

4. The "limiting magnitude" based on a S/N ratio of two is roughly +32.5 magnitude for the camera, +18 for the high resolution spectrograph and +25 for the faint object spectrograph.

5. Man's major role will be that of replacement/repair. Most of the troubleshooting and diagnosis will be done on the ground, therefore a sufficient amount of diagnostic data should be made available.

6. The instruments must be designed:

   a. such that no alignment calibration is performed by the astronaut

   b. to be readily replaced in the SIP. This maintenance concept will be a major driver of the mechanical, electronic and harness design

7. An improved sensor design can:

   a. permit a closer approach to the background limit in the spectrographs

   b. result in lower focal ratios and a smaller package size

   c. improve the resolution of the present designs

   d. ease the thermal constraints on sensors

   e. ease the structural problems of the high resolution camera.

8. Further work is required on the image motion compensation for the high resolution camera.

9. Further work is needed on the near IR photocathode development (III-V compounds).

10. Further work is required on the slit jaw monitor mode of operation and its sensor, and the general problem of target acquisition and image motion monitoring.

11. Additional packaging studies of the 50 by 50 millimeter SEC Vidicon, including cooling, magnetic shielding, and circuitry are required.

12. A study of previous target problems (UVICON) and an investigation of Ebic targets is recommended.

13. A more detailed evaluation of calibration sources should be made.

14. A comprehensive review of the assumptions and the trade-off options available to the astronomer as a result of this study should be made. The astronomers and engineering community should do this in close liaison in order to optimize the SIP design in terms of instrument size performance and cost effectiveness.